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For: METHOD OF ALIGNING A SUBSTRATE, COMPUTER PROGRAM, DEVICE MANUFACTURING METHOD, AND DEVICE MANUFACTURED THEREBY

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SUBMISSION OF PRIORITY DOCUMENT

Attached please find the certified copy of the foreign application from which priority is claimed for this case:

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EUROPE	02256420.7	September 13, 2002

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PILLSBURY WINTHROP LLP
P.O. Box 10500
McLean, VA 22102
Telephone: (703) 905-2000
Facsimile: (703) 905-2500

Customer Number: 00909

Kerry T. Hartman
Registration No. 41818

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Bescheinigung / Certificate / Attestation

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The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. / Patent application No. / Demande de brevet n°

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Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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R C van Dijk

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ASML Netherlands B.V.
De Run 1110
5503 LA Veldhoven
PAYS-BAS

Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Lithographic apparatus and a method of detecting inclination

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Lithographic Apparatus and a Method of Detecting Inclination

The present invention relates to a lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
- a substrate table for holding a substrate having a mark;
- a projection system for projecting the patterned beam onto a target portion of the substrate; and
- an alignment system for detecting alignment between a reference mark and said mark using an alignment beam of radiation.

The term "patterning means" as here employed should be broadly interpreted as referring to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning means include:

- A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.
- A programmable mirror array. One example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The

basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. An alternative embodiment of a programmable mirror array employs a matrix arrangement of tiny mirrors, each of which can be individually tilted about an axis by applying a suitable localized electric field, or by employing piezoelectric actuation means. Once again, the mirrors are matrix-addressable, such that addressed mirrors will reflect an incoming radiation beam in a different direction to unaddressed mirrors; in this manner, the reflected beam is patterned according to the addressing pattern of the matrix-addressable mirrors. The required matrix addressing can be performed using suitable electronic means. In both of the situations described hereabove, the patterning means can comprise one or more programmable mirror arrays. More information on mirror arrays as here referred to can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, and PCT patent applications WO 98/38597 and WO 98/33096, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.

- A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the patterning means as hereabove set forth.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning means may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be

imaged onto a target portion (*e.g.* comprising one or more dies) on a substrate (silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus — commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned, for example, from US 6,046,792, incorporated herein by reference.

In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical

Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens". Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Dual stage lithographic apparatus are described, for example, in US 5,969,441 and WO 98/40791, incorporated herein by reference.

Before exposing the substrate it must be correctly aligned. A mark is therefore provided on the substrate table and an alignment beam is projected towards the mark and partially reflected through an alignment system. The alignment beam is imaged onto a reference mark to detect alignment between the mark and the reference mark.

For some applications, particularly Micro-Electromechanical Systems (MEMS), a pattern is transferred to a substrate, and a further substrate layer is then adhered onto the substrate. In this situation, it is important for the patterns of two substrate layers to be correctly aligned relative to each other, and so the same alignment marks are used for both alignments and exposures. However, the patterns of the first and second substrate layers may still be misaligned. If the exposing beam of radiation is not exactly perpendicular to the substrate the difference in height between the first and second layers means that the surface of the layers intersect the alignment beam at different XY positions. The patterns on the two layers therefore wouldn't be correctly aligned.

It is an object of the present invention to provide a method of detecting inclination of an alignment beam relative to a substrate.

This and other objects are achieved according to the invention in a method of detecting the inclination of an alignment beam relative to a substrate comprising the steps of:

a) providing an alignment beam;
b) providing a substrate table with a mark, the substrate table being substantially perpendicular to the alignment beam;
c) detecting a first position of said mark relative to said alignment beam;
d) moving said substrate table in a direction perpendicular to the top of the substrate table; and
e) detecting a second position of said mark relative to said alignment beam

wherein the difference between said first and second relative positions indicates the inclination of the alignment beam relative to the substrate table.

If the alignment beam is not exactly perpendicular to the substrate table the "vertical" (perpendicular to the surface of the substrate table) movement of the substrate table will generate a lateral movement of the mark with respect to the alignment beam. Once the exact direction of the alignment beam has been determined the angle of the alignment beam can be adjusted to be perpendicular to the substrate table. Alternatively compensation can take place during the exposure of the substrate e.g. by shifting the substrate relative to the patterning means prior to exposure of a second layer. Using this method patterns on second and subsequent substrate layers can be aligned with an accuracy of less than 250 nm.

There is usually a substrate on the substrate table, and the mark may be either on the substrate or on the substrate table itself. If the mark is on the substrate table the substrate table will be aligned in a default position. For applications such as MEMS there is a first substrate with a mark on one side and second substrate adhered to the same side of the first substrate as the mark, and the second substrate has a hole revealing the mark on the first substrate. There is preferably a second mark and the steps of detecting the mark, moving the substrate table, and detecting said mark again are repeated for each mark. Each mark on the substrate table or substrate can be aligned to a separate reference mark on the mask, or alternatively the substrate can be moved and rotated to align to the same reference mark on the mask.

According to a further aspect of the invention there is provided a lithographic projection apparatus as specified in the opening paragraph wherein the substrate table can be moved in a direction substantially parallel to the alignment beam.

Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (*e.g.* with a wavelength of 365, 248, 193, 157 or 126 nm) and EUV (extreme ultra-violet radiation, *e.g.* having a wavelength in the range 5-20 nm), as well as particle beams, such as ion beams or electron beams.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which:

Figure 1 depicts a lithographic projection apparatus according to an embodiment of the invention;

Figure 2 is a diagram showing the alignment mechanics;

Figure 3 shows an alignment beam not perpendicular to the substrate;

Figure 4 shows the alignment offset resulting from the set up of Figure 2;

Figure 5 shows the movement of a substrate table according to the invention;

Figure 6 shows a substrate table with a mark on the substrate table; and

Figure 7 shows a schematic cross section of a composite wafer used to assess the accuracy of the invention.

In the Figures, corresponding reference symbols indicate corresponding parts.

Figure 1 schematically depicts a lithographic projection apparatus according to a particular embodiment of the invention. The apparatus comprises:

- a radiation system Ex, IL, for supplying a projection beam PB of radiation (*e.g.* EUV radiation), which in this particular case also comprises a radiation source LA;
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (*e.g.* a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;
- a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (*e.g.* a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a projection system ("lens") PL (*e.g.* catadioptric lens system) for imaging an irradiated portion of the mask MA onto a target portion C (*e.g.* comprising one or more dies) of the substrate W.

As here depicted, the apparatus is of a transmissive type (*e.g.* has a transmissive mask). However, in general, it may also be of a reflective type, for example (*e.g.* with a reflective mask). Alternatively, the apparatus may employ another kind of patterning means, such as a programmable mirror array of a type as referred to above.

The source LA (*e.g.* a laser-produced or discharge plasma source) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning means, such as a beam expander Ex, for example. The illuminator IL may comprise adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired uniformity and intensity distribution in its cross-section.

It should be noted with regard to Figure 1 that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic

projection apparatus, the radiation beam which it produces being led into the apparatus (e.g. with the aid of suitable directing mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and Claims encompass both of these scenarios.

The beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having traversed the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means (and interferometric measuring means IF), the substrate table WT can be moved accurately, *e.g.* so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, *e.g.* after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. However, in the case of a wafer stepper (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed.

The depicted apparatus can be used in two different modes:

1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (*i.e.* a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;
2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", *e.g.* the y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, M = 1/4 or 1/5). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

Prior to exposure of the substrate, alignment of the mask MA and the substrate W takes place. Complementary reference mark M_1 and mark P_1 are present on the mask MA and substrate W respectively. In Figure 2 an alignment beam AB is projected

through the projection system PL and partially reflected from the mark P_1 through the alignment system AS. The alignment beam is then imaged onto the alignment mark M_1. The alignment of the mark P_1 and alignment mark M_1 can be detected to determine the alignment of the substrate W.

In Figure 3, the substrate consists of a first substrate layer W_A with mark P_1 and a second substrate layer W_B of thickness T bonded to the top of first substrate layer W_A. Second substrate layer W_B has been etched to reveal mark P_1 on first substrate layer W_A beneath. As can be seen, the alignment beam AB is not perpendicular to the top surface of the substrate W. If alignment of the second substrate layer W_B takes place with the alignment beam AB at this angle to the substrate W the measured position of the second substrate layer W_B will differ from the real position of the second substrate layer W_B by an offset Δ, given by the equation:

$$\Delta = \phi . T$$

This can be seen in Figure 4. If printing on the second substrate layer W_B occurs it will be offset from printing on the first substrate layer W_A by an amount Δ.

To detect this offset the substrate table WT is able to move vertically, as shown in Figure 5. To detect a misalignment of the alignment beam AB, the alignment beam is initially focused on mark P_1 and reflected towards reference mark M_1. The substrate table WT is moved to establish correct XY orientation. The position of the image of mark P_1 relative to reference mark M_1 is scanned and the substrate table WT is then moved upwards in the Z direction by up to 100μm. The position of the image of mark P_1 relative to reference mark M_1 is scanned again and the results compared to the first scan. If the image of mark P_1 has moved relative to reference mark M_1 then the alignment beam AB and the substrate table WT are not perpendicular. The inclination of the alignment beam AB is therefore altered to correct this misalignment. The same procedure is repeated in order to check alignment again.

The substrate table WT is then moved so the alignment beam focuses on the second mark P_2, and is again reflected towards reference mark M_1. The substrate table WT is again moved vertically and the angular alignment process repeated.

Instead of moving the substrate table laterally to focus on the second mark W_2 the substrate W could have been rotated. As a further alternative the second substrate mark W2 could focus on a second reference mark M_2.

This alignment process can be repeated for third and subsequent substrate layers, to a total thickness of 2 mm.

Instead of the marks being on the substrate there could alternatively be a mark F_1 on the substrate table as shown in Figure 6. This would allow the substrate table WT itself to be correctly oriented and not be subject to any random errors in the surface of the substrate W.

This procedure is preferably executed before any printing is done on any substrate layer.

To assess the accuracy of this method of detecting inclination a scanning electron microscope was used. The method described above was used to ensure that a substrate layer W_c shown in Fig.7 and the alignment beam were perpendicular. A second substrate layer W_D was adhered to the first substrate layer. The reference mark M_1, together with the perpendicular alignment beam were used to estimate the location of the P_1. At the estimated location of P_1, P_x the second substrate layer is etched to the oxide layer, OL. A cross section of these alignment marks is then scanned using a SEM. The misalignment of the estimated location of P_1, and the action location of P_1 in the direction X is given by the equation:

$$X_T = \frac{(\Delta X_1 + \Delta X_2)}{2}$$

The cross section of the alignment marks must be scanned in at least two perpendicular directions in order to fully calculate the misalignment. Using this assessment technique the invention was shown to result in an overlay between original and estimated mark of <250nm over distances of up to 100 μm.

Whilst specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

CLAIMS:

1. A method of detecting the inclination of an alignment beam relative to a substrate comprising the steps of:

a) providing an alignment beam;
b) providing a substrate table with a mark, the substrate table being substantially perpendicular to the alignment beam;
c) detecting a first position of said mark relative to said alignment beam;
d) moving said substrate table in a direction perpendicular to the top of the substrate table; and
e). detecting a second position of said mark relative to said alignment beam

wherein the difference between said first and second relative positions indicates the inclination of the alignment beam relative to the substrate table.

2. The method according to claim 1 wherein the alignment beam is adjusted to be perpendicular to the substrate table.

3. The method according to either claim 1 or claim 2 wherein the mark is on the substrate table.

4. The method according to any one of the preceding claims wherein there is a substrate on the substrate table.

5. The method according to any claim 4 wherein the mark is on the substrate.

6. The method according to claim 5 wherein there is a first substrate with a mark on one side and a second substrate adhered to the same side of the substrate as the mark, and the second substrate comprises a hole revealing the mark on the first substrate.

7. The method according to any one of the preceding claims wherein there is a second mark.

8. The method according to claim 7 wherein steps c,d and e are repeated for the second mark.

9. A lithographic projection apparatus comprising:

- a radiation system for providing a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
- a substrate table for holding a substrate having a mark;
- a projection system for projection the patterned beam onto a target portion of the substrate; and
- an alignment system for detecting alignment between a reference mark and said mark using an alignment beam of radiation,

wherein the substrate table can be moved in a direction substantially parallel to the alignment beam.

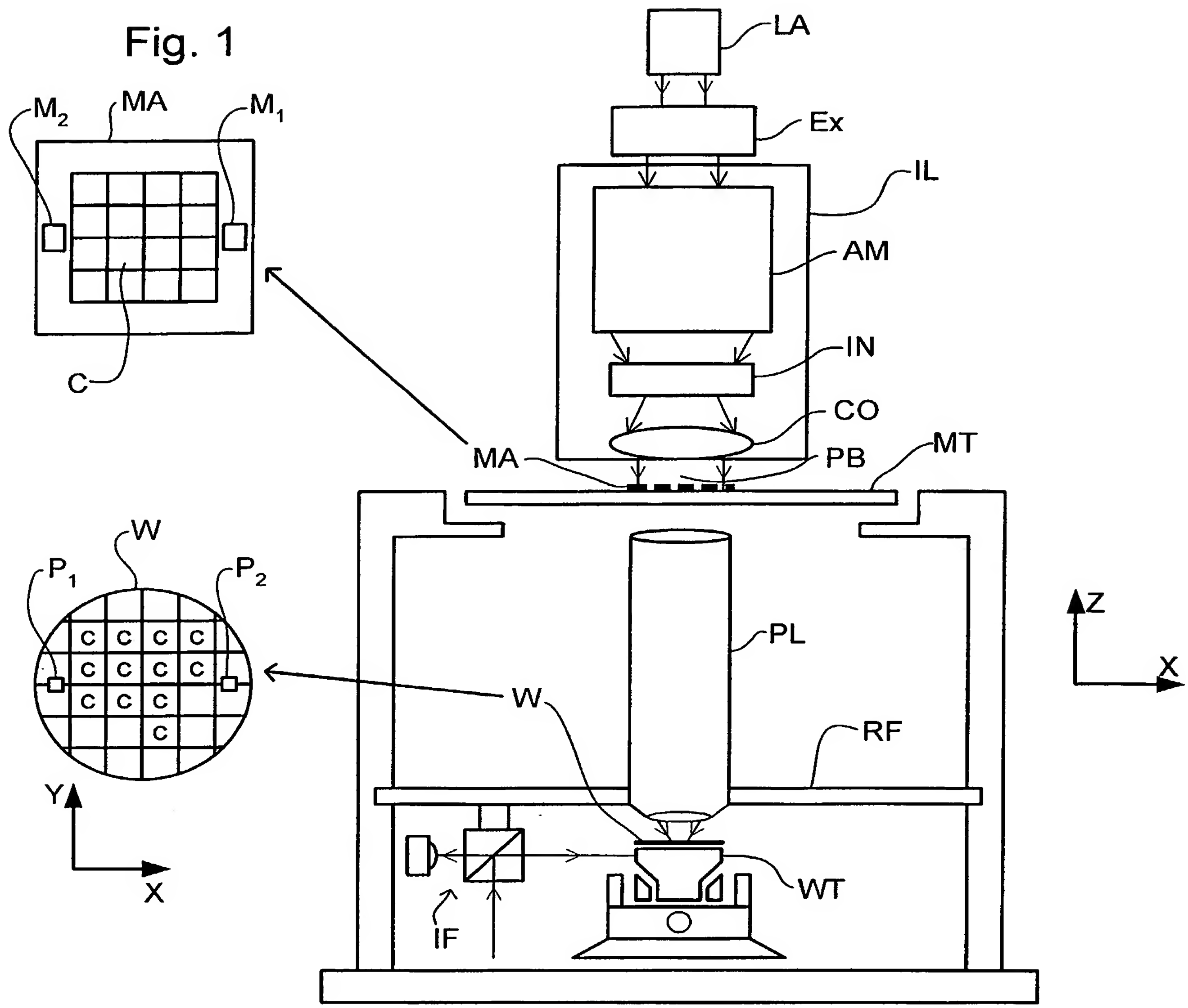
ABSTRACT

Lithographic Apparatus and a Method of Detecting Inclination

While the alignment beam is focused on a mark on the substrate table the substrate table is moved substantially perpendicularly to the alignment beam. If the image of the mark moves relative to a reference mark, then the substrate and the alignment beam are not perpendicular.

Fig. 5

Fig. 1


M2
MA
M1
C
LA
Ex
IL
AM
IN
CO
MA
PB
MT
W
P1
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c c c c
c c c
c
Z
X
PL
W
RF
Y
X
WT
IF

Fig. 2

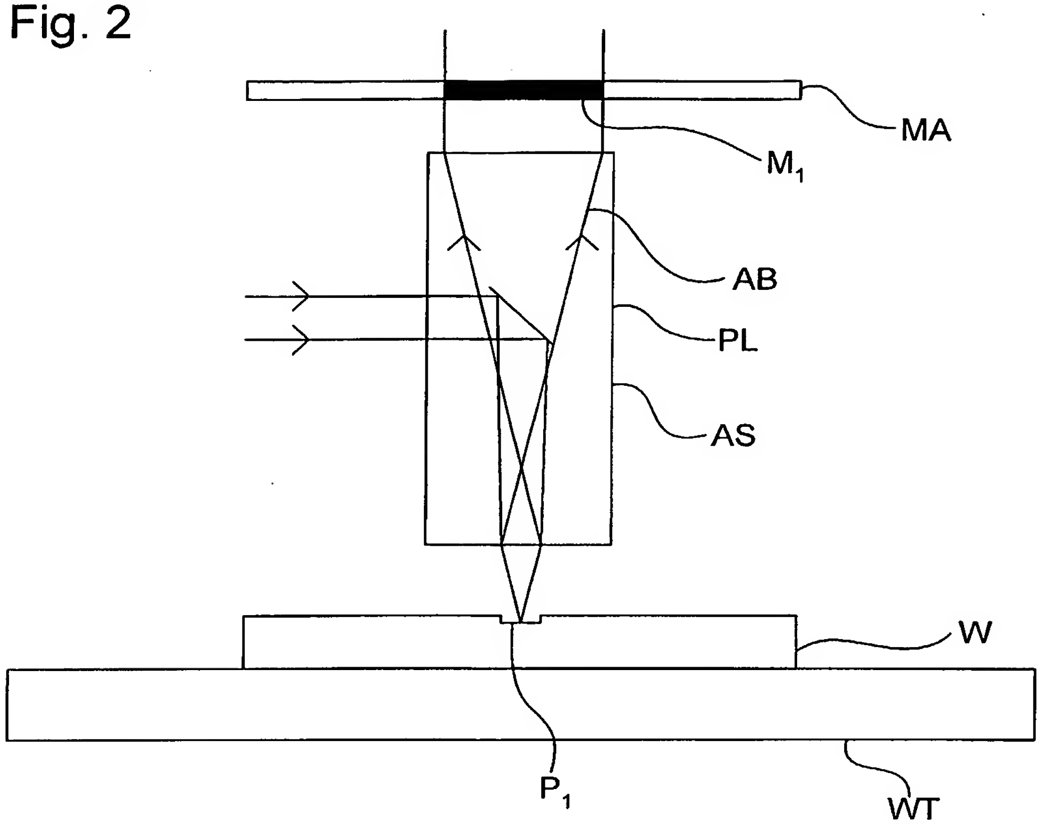

Fig. 3

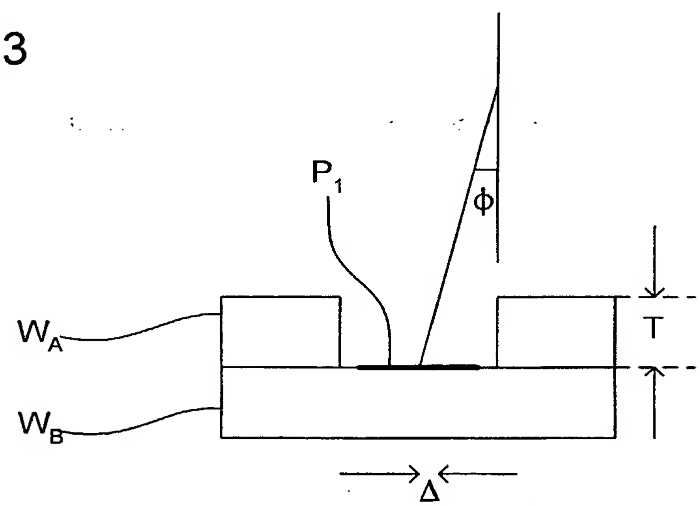

Fig. 4

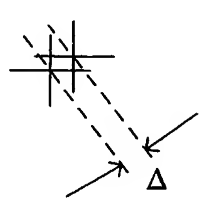

Fig. 5

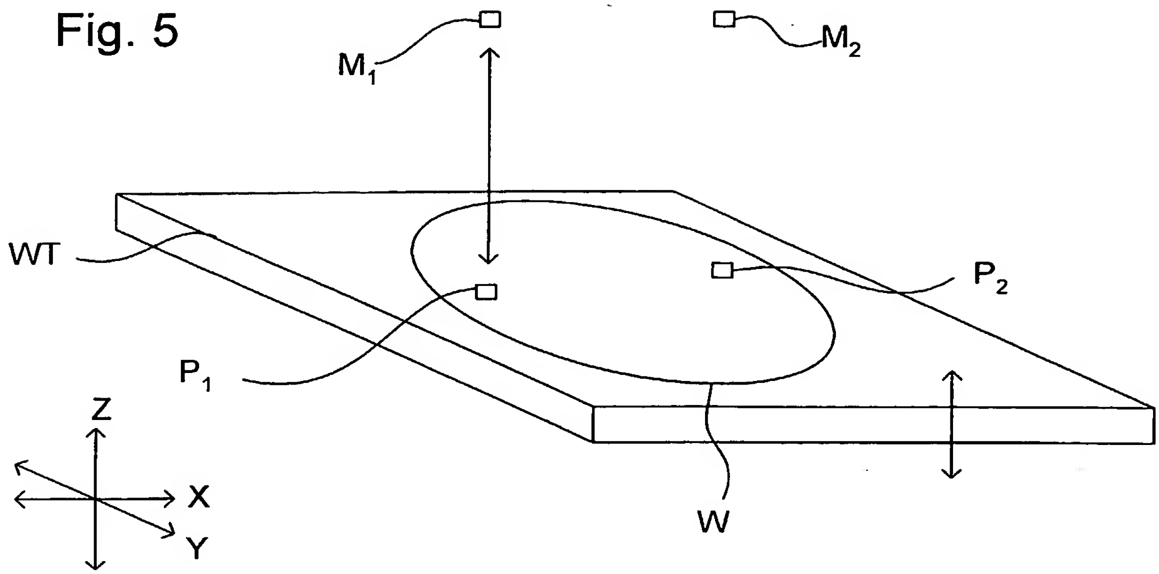

Fig. 6

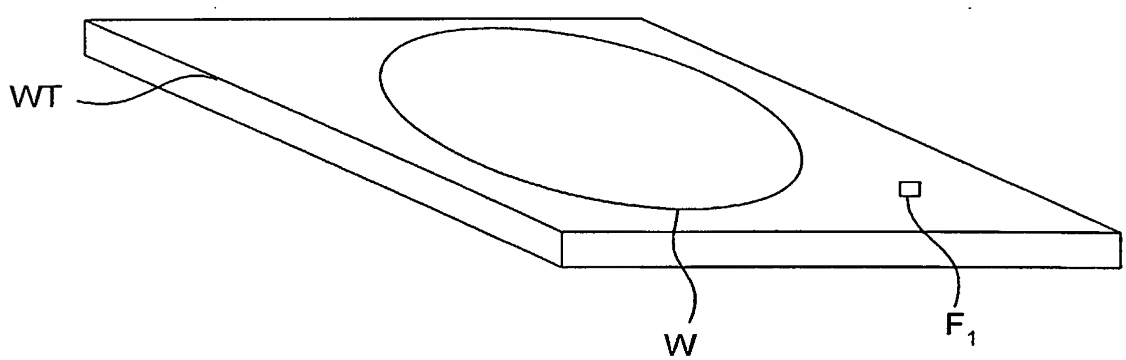

Fig. 7